CS15210: Data Transmission

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(based on slides by Mike Clarke)

Previously, in CS15210...

- Data Terminal Equipment (DTEs) and
  Data Circuit-Terminating Equipment (DCEs)
- Modems, modulation, and demodulation:
  - amplitude (ASK), frequency (FSK), phase (PSK, 4-PSK)
  - constellation diagrams
- Bit and baud rate
- A brief intro to Nyquist's Theorem...

Logarithms ...

$$\boxed{\log_a x = b}$$

If $a^b = x$,
then b is the logarithm of x to the base a

Special cases:

$$\log 1 = 0$$

$$\log_a a = 1$$

Useful tricks:

$$\log_a x + \log_a y = \log_a (x \times y)$$

$$\log(x/y) = \log x - \log y$$

$$\log(1/x) = -\log x$$

Contents

The PSTN

- PSTN: Public Switched Telephone Network
- The PSTN was designed to handle voice communication **not** data
- This means that bandwidth is *deliberately* limited at the exchanges
  - Voices only have a particular range of frequencies
  - This is why music sounds ‘tinny’

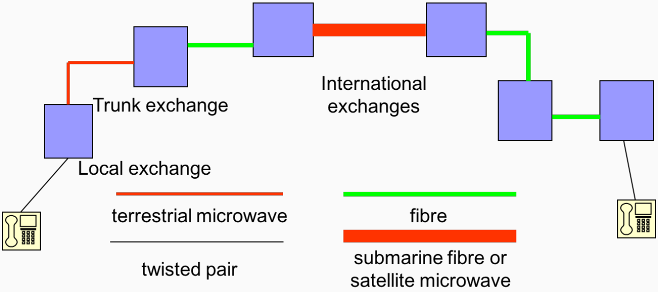
The PSTN

- Using it for data means:
  - we need special equipment (modems)
  - channel capacity is limited
  - line quality (signal to noise ratio) is poor (because of the equipment in the exchanges)
- Nevertheless, it is everywhere and so it is used a lot for data communication
- We now have much better equipment
  - broadband, fibre to the home, etc.
  - much better than it used to be
  - the PSTN is much more digitally-oriented than it used to be

Switching

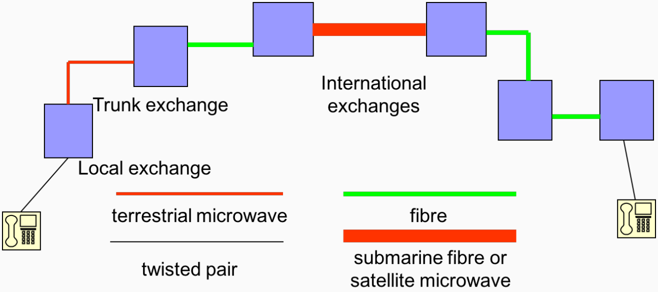
- The process of setting up a connection (a channel) between two stations is called switching
- A unit that does this is called a switch
- A conventional telephone exchange is an example of a switch - you have multiple connections coming in, and channels are being created between two locations
- It used to be literal switching of cables
- Modern and older usage both referred to the fact that connections are being made

Structure of the PSTN



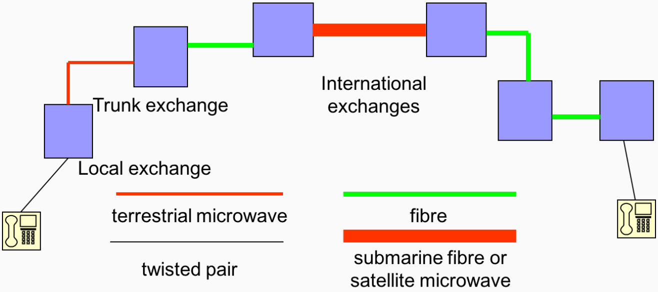
- **Local loop**: subscribers (consumers) are linked to the local exchange by twisted pairs, fibre, etc.
  - In the UK, (BT) Openreach manage the infrastructure and sell their services to companies like BT, Sky, TalkTalk, etc.

Structure of the PSTN



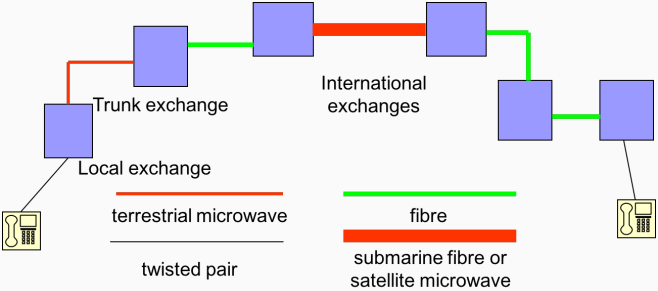
- Local exchanges are connected to **trunk exchanges**
    - A trunk exchange is an exchange that is only connected to other exchanges

Structure of the PSTN



- Trunk exchanges are connected together by trunk lines
  - In the UK, trunk lines and connections between trunk exchanges and local exchanges are usually fibre but may be terrestrial microwave

Structure of the PSTN



- International connections are usually fibre (undersea where necessary) but may be satellite microwave

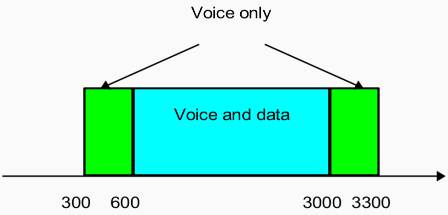
Bandwidth

- **The bandwidth of a communications link** is the range of frequencies *that it can* transmit satisfactorily
  - Depends on the transmission medium, the terminal equipment and the length of the link
- **The bandwidth of a signal** is the range of frequencies *needed* to transmit it satisfactorily

Channel Capacity

- **The channel capacity** is number of bits per second that can be transmitted over a link
- Depends on:
  - the bandwidth of the link
  - the modulation technique used (e.g. ASK, FSK, PSK, ...)
  - and the signal-to-noise ratio

Telephones



- A traditional telephone circuit can only transmit signals in the range 300 Hz to 3300 Hz
  - bandwidth = 3000 Hz
- For data transmission, only 600 Hz to 3000 Hz was used
  - bandwidth = 2400 Hz
- Circuits installed recently usually have greater bandwidth

Back to Nyquist's Theorem...

Ignoring the effects of noise,
the **maximum channel capacity**
that can be achieved on a channel is:

$$\boxed{2 \times B \log_2 M \ \mathrm{bit\,s^{-1}}}$$

B = bandwidth
M = number of signalling events

Example

If we assume that the number of signalling levels used by a piece of equipment that is transmitting over a domestic phone line is 2^6, what is the channel capacity?

$$\boxed{2 \times B \log_2 M \ \mathrm{bit\,s^{-1}}}$$

Example

If we assume that the number of signalling levels used by a piece of equipment that is transmitting over a domestic phone line is 2^6, what is the channel capacity?

$$\boxed{2 \times B \log_2 M \ \text{bit}\,\text{s}^{-1}}$$

$$\text{M} = 2^6 = 64$$
$$\text{B} = 2400$$

Example

If we assume that the number of signalling levels used by a piece of equipment that is transmitting over a domestic phone line is 2^6, what is the channel capacity?

$$\boxed{2 \times 2400 \log_2 64 \text{ bit s}^{-1}}$$

$$\log_a x = b \quad \rightarrow \quad a^b = x$$

$$\log_2 64 = ? \quad \rightarrow \quad 2^6 = 64$$

Example

If we assume that the number of signalling levels used by a piece of equipment that is transmitting over a domestic phone line is 2^6, what is the channel capacity?

$$\boxed{28800\ \mathrm{bit\,s^{-1}}}$$

$$2 \times 2400 \times 6 = 28800$$

Before 56k, this was the standard capacity

Back to Nyquist's Theorem...

Ignoring the effects of noise,
the maximum channel capacity
that can be achieved on a channel is:

$$\boxed{2 \times B \log_2 M \ \mathrm{bit\,s^{-1}}}$$

B = bandwidth
M = number of signalling events

Signal-to-Noise Ratio

$$\boxed{10\log_{10}(S/N)\ \text{dB}}$$

S = average power of the signal
N = average power of the noise

Often quoted as a measure of the quality of a channel, measured in decibels (dB)

Shannon-Hartley Theorem

The **maximum channel capacity**
that can be achieved on a channel
(regardless of the number of signalling levels) is:

$$\boxed{B \log_2(1 + 10^{(r/10)}) \text{ bit s}^{-1}}$$

B = bandwidth
r = signal-to-noise ratio

Example

For the PSTN, $B = 2400$ and $r = 40$ dB.
The maximum channel capacity is therefore:

$$\boxed{2400 \log_2(1 + 10^{(40/10)})\ \mathrm{bit\,s^{-1}}}$$

r = 40
B = 2400

Example

For the PSTN, $B = 2400$ and $r = 40$ dB.
The maximum channel capacity is therefore:

$$\boxed{2400 \log_2 \left(1 + 10^{\left(40/10\right)}\right) \text{ bit s}^{-1}}$$

$$10^{\left(40/10\right)} = 10^4 = 10000$$
$$1 + 10000 = 10001$$

Example

For the PSTN, $B = 2400$ and $r = 40$ dB.
The maximum channel capacity is therefore:

$$\boxed{2400 \log_2(10001)\ \mathrm{bit\,s^{-1}}}$$

$$10^{(40/10)} = 10^4 = 10000$$
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Example

For the PSTN, $B = 2400$ and $r = 40$ dB.
The maximum channel capacity is therefore:

$$\boxed{2400\log_2(10001)\ \mathrm{bit\,s^{-1}}}$$

$$\log_2 10001 = \frac{\log_{10} 10001}{\log_{10} 2} = 13.33$$

Example

For the PSTN, $B = 2400$ and $r = 40$ dB.
The maximum channel capacity is therefore:

$$\boxed{31891 \text{ bit}\,\text{s}^{-1}}$$

$$2400 \times 13.33 = 31891$$
$$(32\,\text{kbit}\,\text{s}^{-1})$$

A Screen of Data

Example: a screen of data is made up of an array of dots (pixels), 768 dots high by 1024 dots wide

A Screen of Data

Each pixel has 256 settings (0–255 levels of grey).

How long does it take to transmit the screen over a telephone line?

A Screen of Data

Total number of bits is $768 \times 1024 \times 8 = 6,291,456$

A Screen of Data

At the theoretical maximum rate for a 2400 Hz, 40 dB PSTN line,

it would take $6291456/31891 = 197$ secs

i.e. just over three and a quarter minutes

A Screen of Data... in Colour

Each pixel has $256 \times 3 = 768$ settings (0–255 levels of RGB).

How long does it take to transmit the screen over a telephone line?

A Screen of Data... in Colour

Total number of bits is $768 \times 1024 \times 8 \times 3 = 18,874,368$

A Screen of Data... in Colour

At the theoretical maximum rate for a 2400 Hz, 40 dB PSTN line,

it would take $18874368/31891 = 592$ secs

i.e. nearly 10 minutes!

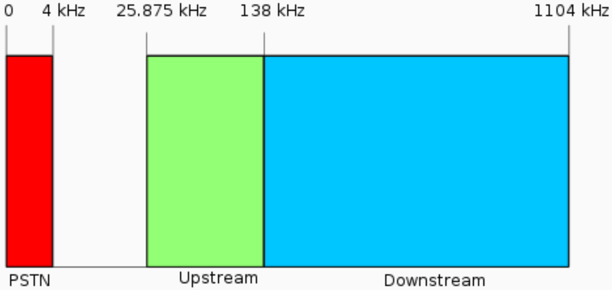
Data Compression

We can do better by using *data compression*, which exploits the fact that one pixel is very likely to be the same as its neighbours

Data Compression

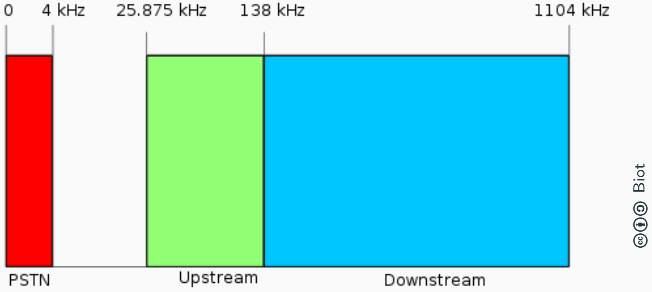
Can easily reduce the number of bits to be transmitted by a factor of 8, but this is very lossy

But what about ADSL (broadband)?



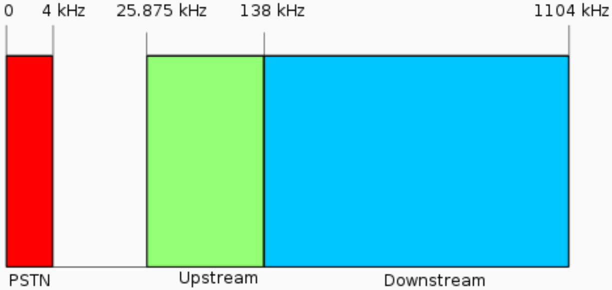
But PTSN was not designed for data...

But what about ADSL (broadband)?



That's why you have to be close to the exchange to get maximum benefit - the better your signal-to-noise ratio, the bigger the maximum potential channel capacity

But what about ADSL (broadband)?



ADSL (Asymmetric Digital Subscriber Line)
refers to the fact that the download bandwidth (hence speed) is
greater than the upload bandwidth (cf SDSL)

The important things to remember:

- Understand the structure of the PSTN
- Bandwidth vs Channel Capacity:
  - Bandwidth of a communications link: the range of frequencies *that it can* transmit
  - The bandwidth of a signal: the range of frequencies *needed* to transmit
  - Channel capacity: number of bits per second that can be transmitted over a link

The important things to remember:

- Nyquist's Theorem: maximum channel capacity regardless of noise
- Shannon-Hartley Theorem: maximum channel capacity regardless of signalling levels
- ADSL and sending data

Next time...

Multiplexors and Switching
(how the data goes through the network)